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# RAIL STRUCTURE INTERACTION ANALYSIS FOR BRIDGE ACROSS RIVER VATRAK IN THE STATE OF GUJARAT, INDIA

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## Abstract

Continuous Welded Rails (CWR) are widely used these days for its benefits like reduced maintenance, enhanced track safety etc. While using CWR, it is to be ensured that any interaction between the rail and bridge due to temperature and rail traffic loads is within the limits specified in UIC 774-3R. The interaction mainly depends on the stiffness of various elements of bridge, resistance offered by track structure to deformation, the continuity of rails and introduction of expansion joints in between them. This current study was carried out for continuous welded rail over Railway Bridge across river Vatrak in Gujarat, India for Dedicated Freight Corridor Corporation (DFCC) by adopting different options such as altering the bearing arrangements and introduction of switch expansion joints (SEJ). Rail structure interaction (RSI) analyses were carried out using industry standard finite element method (FEM) software package and also as per the requirements of UIC 774-3R code of practice. The present paper further studies the resulting additional stresses and displacements due to the above RSI analyses for various options to arrive at acceptable solution satisfying UIC 774-3R codal requirements.

*Keywords: track, continuous welded rails, rail interaction, switch expansion joints, rail free fasteners*

## 1 Introduction

Rail structure interaction (RSI) is crucial in railway bridge design, especially with the prevalence of continuously welded rails (CWR) in modern systems [1]. Deformation of the deck due to structural expansion joints leads to additional stresses in rails and longitudinal forces in the substructure, causing track instabilities [2]. Nonlinear analyses, as per UIC 774-3R recommendations, are essential for assessing RSI effects from thermal loading, traction, braking, and vertical train loads. Beyond UIC limits, control measures include:

- Employing stiffer bridge components for track safety, considering techno-economic factors [3].
- Modifying bearing disposition to alter expansion length and reduce rail stresses [4].
- Introducing switch expansion joints (SEJ) to accommodate rail movement and decrease stresses.
- Installing low toe load fasteners where conventional SEJs are insufficient.

Research and trials for the Western Dedicated Freight Corridor Corporation (WDFCC) project involved over 40 bridges, focusing on accommodating 32.5-ton axle loads and double-stack containers. Drawing on this experience, the paper outlines solutions to mitigate interaction effects on a critical bridge over the Vatrak River, Gujarat, India. Adherence to UIC 774-3R and IRS Bridge Rules, including Corrigendum slip no: 45 dated 24.09.2013, guides the analysis [5].

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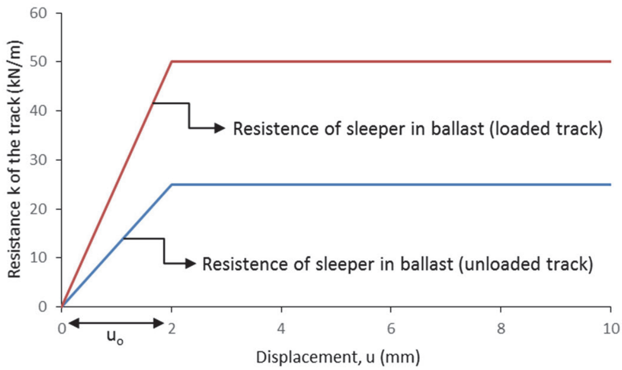



**Figure 1** Longitudinal resistance of the track as a function of longitudinal displacement

## 2 UIC rail structure interaction limitations

UIC 774-3R code of practice explains the interaction between the bridge and the track by bi-linear relationship. The resistance of the rail to longitudinal displacement is a function of displacement of rail relative to supporting structure and the loading on the track. The resistance increases for lower displacements and remains constant after reaching a certain magnitude of displacement. The graph showing the bilinear behaviour of the track as per UIC 774-3R is as shown in Figure.1. The graph shows the displacement between plastic and elastic zone is 2mm for ballasted track. The value of track resistance for computations is taken as 25kN/m for unloaded condition and 50kN/m for loaded condition of the ballasted track [2]. The design criteria to be satisfied for CWR is per clause 1.7.2 of UIC 774-3R.

## 3 Description of bridge

The railway bridge is an eight-span simply supported structure, spanning 385.6 meters, and accommodating two ballasted tracks. Its superstructure consists of two post-tensioned box girders, each 48.2 meters long and 3.5 meters high, supporting a 250 mm thick cast-in-situ deck slab with a 90 mm wearing coat at the track centreline. Concrete grade for the box girder is 55 MPa. The track is connected via ballast, supported by four spherical bearings per superstructure, transferring forces to the substructure. Substructure comprises two cantilever abutments and seven twin pier systems, each supported by pile foundations. Abutment is supported by a 28-pile system, piers by a 12-pile system, each with 1.5 meters diameter. Concrete grade for substructure is 35 MPa. Cross-sectional views of superstructure, abutment, and pier are depicted in Figures 6, 4, and 5 respectively.

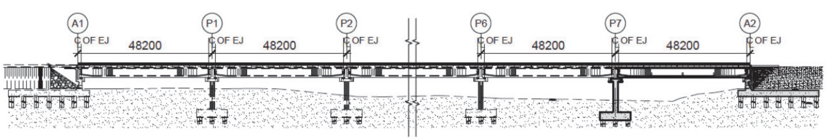



**Figure 2** Elevation of the bridge

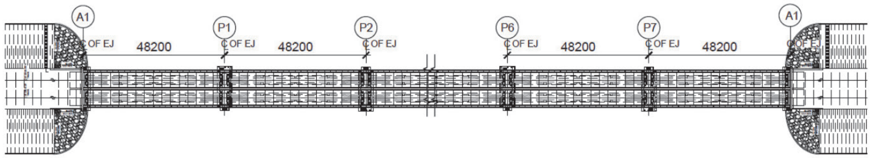



**Figure 3** Plan of the bridge

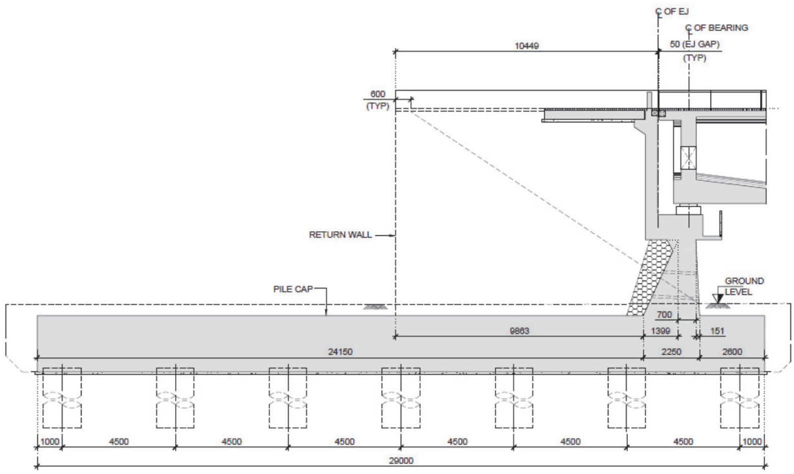



**Figure 4** Cross section view of abutment

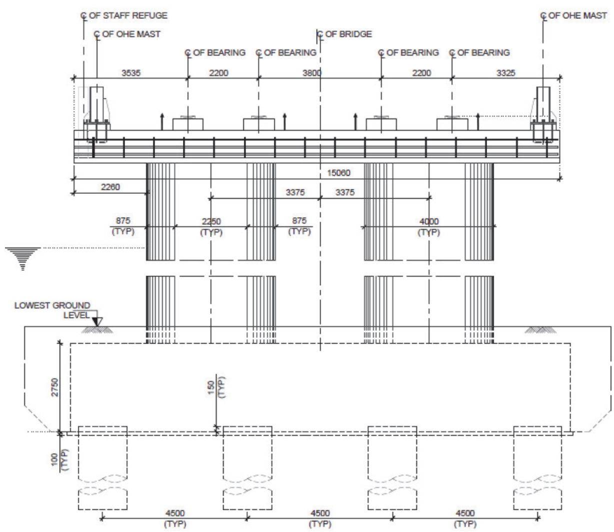



**Figure 5** Cross section view of Pier

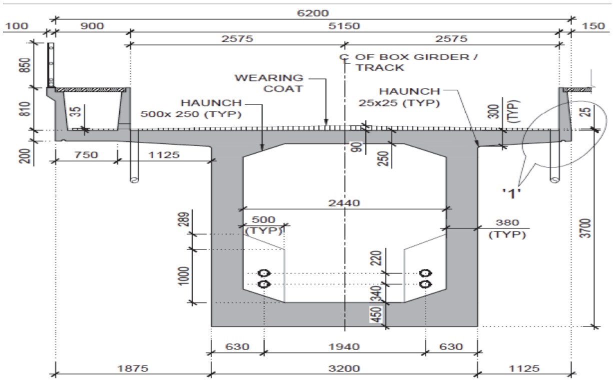



**Figure 6** Cross section of superstructure

## 4 Finite-element model

Nonlinear RSI analysis of the eight-span bridge was conducted using iterative procedures to satisfy all boundary conditions. A finite element model was developed in MIDAS Civil software, validated following UIC 774 3R guidelines. The embankment length on each side of the bridge is 150m. Discrete beam elements represent the track and deck, with a maximum element length of 1m for accuracy. The track-deck connection is modelled using multi-linear elastic springs to capture load-displacement relations, as depicted in Figure 1 by ballast, the longitudinal behaviour of the track-deck is modelled by multi linear elastic springs which captures load displacement relation as shown in Figure 1.
The deck is connected to bearings via rigid links, while the superstructure sits atop elastic-bearing representations with assigned longitudinal stiffness. The entire substructure is modelled with rigid links connecting bearing bottoms to pier/abutment caps, pier/abutment bottoms to pile caps, and pile caps to pile heads. Piles are modelled to their depth of fixity, with fixed soil spring supports provided.

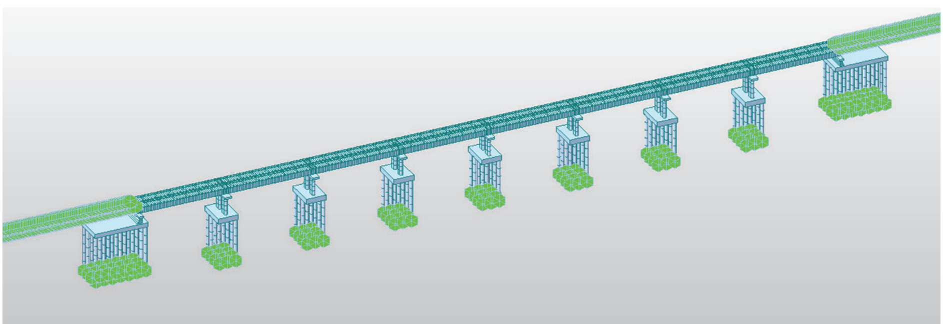


**Figure 7** Finite Element model of the bridge

For the case study the bridge model was done with different bearing arrangements listed below:
In table 1 FX represents fixed bearing and FR represents free bearing arrangements. Case 1 bearing arrangements is adopted in such a way that one abutment is fixed, and other abutment is free, in case 2 both abutments are fixed and centre pier P4 is free. (Refer table 1)
For case 3 SEJ is introduced at one end of abutment and for case 4 SEJ is introduced at both end of abutments. Both these cases are following the same bearing arrangements as case 2. (Refer table 1)

**Table 1** Bearing arrangement considered for different cases.

| Cases | Track | End | A1 | P1 to P3 | | P4 | | P5 to P7 | | A2 | End |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | UP | - | FX | FR | FX | FR | FX | FR | FX | FR | - |
| | DN | - | FX | FR | FX | FR | FX | FR | FX | FR | - |
| 2 | UP | - | FX | FR | FX | FR | FR | FX | FR | FX | - |
| | DN | - | FX | FR | FX | FR | FR | FX | FR | FX | - |
| 3 | UP | SEJ | FX | FR | FX | FR | FR | FX | FR | FX | - |
| | DN | SEJ | FX | FR | FX | FR | FR | FX | FR | FX | - |
| 4 | UP | SEJ | FX | FR | FX | FR | FR | FX | FR | FX | SEJ |
| | DN | SEJ | FX | FR | FX | FR | FR | FX | FR | FX | SEJ |

## 5 Loading

The analysis covered thermal, vertical, braking, and traction loads. Thermal and live loads were initially analysed separately and then combined. For thermal loads, ballast longitudinal resistance is constrained by unloaded track limits, while for live loads, it's limited by loaded track resistance. Figure 1 illustrates ballasted track longitudinal resistance.
The maximum uniform variation of temperature in the deck is considered as +/- 35 degree Celsius. In case of CWR a variation in temperature of the track does not cause interaction effect, so variation in temperature of track not considered.
Live loads conform to 32.5t high axle DFC loading per IRS Bridge rules Appendix XXV [5]. A uniform vertical load of 158.191kN/m over a maximum loaded length of 685.6m, braking load of 19.77kN/m over 686.5m, and traction force of 37.35kN/m over 33.06m were considered. Vertical loads apply to both tracks, while braking and traction apply to separate tracks.

## 6 Results and comments

The model was analysed for different bearing arrangements and this section summarizes the findings.

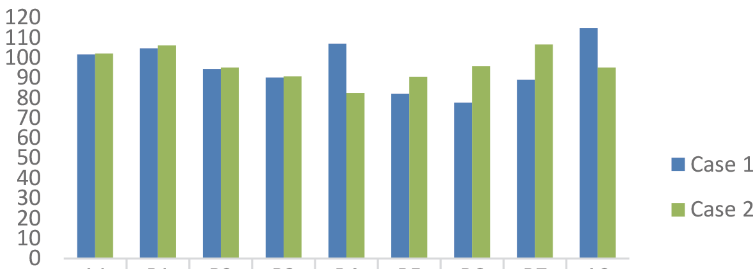
**Case1**:
The maximum rail stress due to temperature is observed near the free abutment, with a value of 30.5 MPa. Additionally, the maximum additional rail tensile stress is recorded at 114.0 MPa, while the maximum compressive stress is 81.69 MPa. These maximum stresses are concentrated near the free abutment. The maximum longitudinal relative displacement between the rail and deck is found to be 4.85 mm. Furthermore, the horizontal displacement of the deck due to braking and traction reaches 9.64 mm, and the maximum horizontal displacement due to vertical bending reaches 14.2 mm. It is noted that the stresses and displacements exceed the allowable limits stipulated by provisions in code.

**Case 2**:
The maximum rail stress due to temperature is found to be 31.5 MPa and is located near the central pier, which is free. Additionally, the maximum additional rail tensile stress is observed at 106.5 MPa, while the maximum compressive stress is 59.8 MPa. The compressive stresses are directed towards the free pier.
The maximum longitudinal relative displacement between the rail and deck is observed to be 4.81 mm. Furthermore, the horizontal displacement of the deck due to braking and traction reached 7.44 mm, and the maximum horizontal displacement due to vertical bending reached 12.01 mm.

Figure 8 and Figure 9 depict the comparison of stresses with fixed-free support and fixed-fixed support. When the support condition was altered from fixed-free to fixed-fixed with an intermediate pier as free, the maximum additional rail compressive stresses reduced by 27% and tensile stresses by 7%. The displacements also indicate a reduction in value compared to the fixed-free support condition. However, it is noted that the stresses and displacements exceed the allowable limits as per the code.

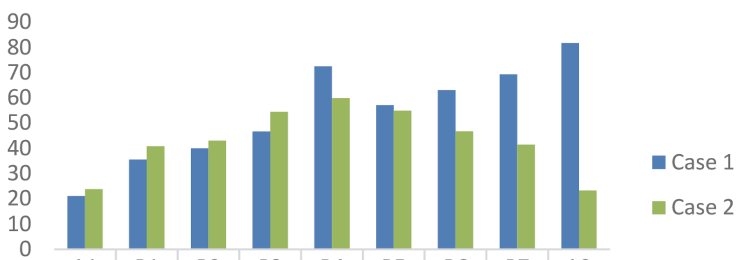
**Case 3**:
It is found that the displacement criteria are not met when SEJ was introduced at one end side. Maximum longitudinal relative displacement between the rail and deck is found to be 4.22mm. The horizontal displacement of the deck due to braking and traction reached 12.22mm which exceeds the allowable limits.

**Case 4**:
The horizontal displacement of the deck due to braking and traction is observed to be 12.22mm which is within the allowable limits of displacement when SEJ is introduced on the rail at both sides of the deck. This configuration satisfies the provisions of code.




| | A1 | P1 | P2 | P3 | P4 | P5 | P6 | P7 | A2 |
|---|---|---|---|---|---|---|---|---|---|
| Case 1 | 101 | 105 | 94 | 90 | 107 | 82 | 78 | 89 | 115 |
| Case 2 | 102 | 106 | 95 | 91 | 82 | 90 | 96 | 107 | 95 |

**Figure 8** Maximum Tensile stress in MPa at support locations




| | A1 | P1 | P2 | P3 | P4 | P5 | P6 | P7 | A2 |
|---|---|---|---|---|---|---|---|---|---|
| Case 1 | 21,09 | 35,50 | 39,94 | 46,70 | 72,47 | 57,10 | 63,10 | 69,34 | 81,69 |
| Case 2 | 23,83 | 40,80 | 43,00 | 54,50 | 59,80 | 54,86 | 46,73 | 41,40 | 23,28 |

**Figure 9** Maximum compressive stress in MPa at support locations

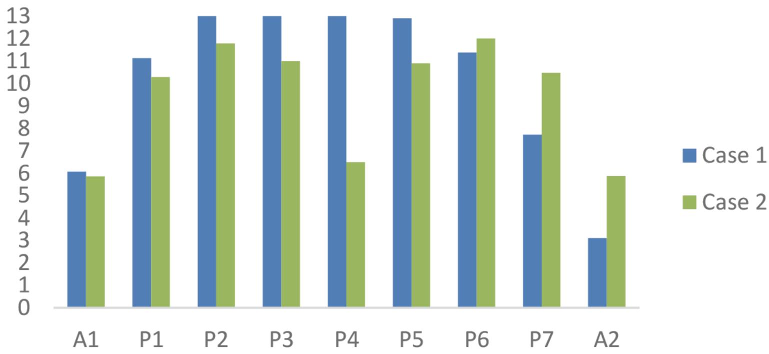



**Figure 10** Deck end rotational displacement of deck for vertical bending for case 1 and 2.

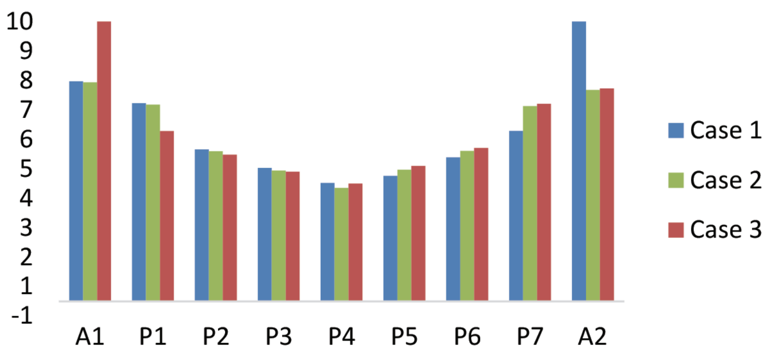



**Figure 11** Absolute maximum displacement of deck for case 1, 2 and 3

## 7 Conclusion

In railway bridge design, managing additional stresses from deck expansion, braking/traction-induced displacements, and vertical bending is crucial, particularly in long spans to prevent track instabilities. Optimizing stiffness through bearing arrangement adjustments is preferable over structural stiffening for cost-effectiveness. This study investigates minimizing interaction effects by modifying bearing disposition and introducing switch expansion joints (SEJ). Key findings:

- Adjusting bearing arrangements, notably to fixed-fixed, reduces maximum longitudinal and horizontal displacements due to braking/traction and vertical bending, channelling temperature-induced compressive stresses towards the free pier.
- Exceeding stress and displacement limits with fixed-free and fixed-fixed support necessitates SEJ implementation on continuously welded rails (CWR) to enable longitudinal movement, particularly vital for longer spans.
- SEJ incorporation on both abutment sides further diminishes displacements, ensuring adherence to UIC 774-3R criteria without altering structural dimensions, as evidenced in the Vatrak River railway bridge design for the DFCC project.
- Furthermore, exploring low toe load or rail-free fasteners at the bridge location offers alternative solutions to mitigate significant horizontal forces from rail structure interaction.

## References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[5] Indian Railway Standards - Bridge Rules: Rules specifying the loads for design of super-structure and sub-structure of bridges and for assessment of the strength of existing bridges